RELATIONSHIPS BETWEEN PROTEIN AND ENERGY CONSUMED FROM MILK REPLACER AND STARTER AND CALF GROWTH AND FIRST LACTATION PRODUCTION PERFORMANCE OF HOLSTEIN DAIRY COWS

A THESIS

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But ask the animals, and they will teach you, or the birds in the sky, and they will tell you; or speak to the earth, and it will teach you, or let the fish in the sea inform you. Which of all these does not know that the hand of the Lord has done this? In his hand is the life of every creature and the breath of all mankind. – Job 12:7

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Abstract

The objective of this study was to determine metabolizable energy (ME) and protein consumed from both milk replacer and starter and its relationship to calf growth and first lactation 305-day milk and milk components. Data was collected from Holstein dairy calves (n = 4,534) raised at the Southern Research and Outreach Center (SROC) from 2004-2014 to assess whether early life protein and ME consumption were related to calf growth. First-lactation data was analyzed for 3,627 cows from the calf dataset. Effects of birth season on protein and ME consumption were also analyzed. The results suggest that early life protein and ME consumption has a positive correlation with calf average daily gain (ADG) as well as first-lactation 305-d milk and milk components. The results also suggest that birth season plays a role in ME and protein consumed, with calves born in the fall and winter consuming more ME and protein than calves born in the spring and summer months.

Table of Contents

List of Tables

Manuscript 1

Manuscript 2

List of Figures

Manuscript 1

Manuscript 2

Introduction

Milk Replacer

In the United States, over 85% of heifers are fed milk replacer (MR) as a part of their preweaning diets (NAHMS, 2011). To allow for proper digestion, MR must be formulated with ingredients the digestive system of a young calf can handle (Heinrich et al., 1995). MR formulation contains a protein source (milk or alternative), fat source (tallow, lard, or grease), vitamins, minerals, and additives. Protein source is the most expensive portion of an MR formulation (Quigley et al., 2003), the most costly protein being those derived from a milk source. These milk proteins include Whey Protein Concentrate (WPC), Dried Skim Milk (DSM), or Delactose Whey. A study done by Terosky et al. (1997) showed that whey is a more economical option when it comes to milk proteins, while still providing proper nutrition to the calf. Whey proteins are highly digestible in addition to containing the amino acid profile needed for the calf when methionine (Met) is supplemented (Davis and Drackley, 1998).

Due to the high cost of using milk proteins, many studies have looked into alternative protein sources such as those that are plant derived or derived from animal manufacturing by-products (Morrill et al., 1995; Quigley et al., 2002; Quigley et al., 2003; Raeth et al., 2016; Vasquez et al., 2017). Blood proteins are a common addition to milk replacer. Spray-dried plasma proteins are processed to ensure the functional proteins remain intact. These functional proteins include peptides, albumin, and IgG (Quigley et al., 2003). A study done by Quigley et al. (2003) as well as others (Morrill et al., 1995; Vasquez et al., 2017) showed that biologically active proteins found in spray-dried plasma are valuable to animals, especially during periods of stress (Quigley et al., 2003).

A recent study conducted by Vasquez et al. (2017) showed that plasma protein is a viable alternative when supplemented in MR to account for 25% or less of the total crude protein (CP).

Plant based proteins are also an alternative protein option. Wheat gluten (WG) derived from either wheat or wheat flour can be beneficial to calves when used in MR (Terui et al., 1996). A study done by Terui et al. (1996) showed that growth was not significantly different among calves that were fed a 20% CP MR with or without WG. The calves tended to gain more body weight (BW) when 33% of the total CP was from WG.

Soy protein is another plant based alternative protein. However, there are anti-nutritional properties associated with soy, due to the presence of antigens (Seegraber et al., 1985). A study conducted by Seegraber et al. (1985) looked into these antigens and trypsin inhibitors (TI) and showed they were a significant factor in the problems faced when feeding soy protein MR. A study done by Kanjanapruthipong et al. (1998) showed that soy protein MR can be supplemented with additional threonine, methionine and lysine to improve calf performance on such diets.

Starter and Starter Intake

The transition from liquid feed to solid feed is crucial in order to minimize calf mortality and morbidity and the intake of dry feed is beneficial to the pre-weaned calf (Anderson et al., 1987; Drackley et al., 2008). In addition to milk replacer feeding and management manipulation to increase starter intake, forages and other dietary changes can increase starter intake (Khan et al., 2011; Mirzaei et al., 2017). A study done by Khan et al. (2011) showed that supplementing chopped hay to calves fed high volumes of milk (such as intensive feeding program) at an early age can improve starter intake and rumen development. In the study done by Khan et al. (2011), orchard grass hay was used with a mean particle size of 1.2 ± 0.4 cm. Barley grain and corn silage can increase starter intake as well (Mirzaei et al., 2017).

Starters typically are found in two different forms: Textured and Pelleted. Studies have looked into the benefits of feeding one over the other (Bach et al., 2007; Franklin et al., 2003). The study done by Franklin et al. (2003) found that calves fed a texturized pellet consumed 72% more starter than calves offered a pelleted starter and required fewer days to achieve 0.68 kg/d of intake of dry feed. In addition, Bach et al. (2007) findings also show that pelleted starter may result in less dry feed intake with less ADG between weaning and two months. However, final BW was similar across treatments, indicating that pelleted feed may have better feed efficiency.

Starters also contain molasses or molasses based products to help with palatability. The level of molasses is something to note, as most starters contain 5-12% molasses (Lesmeister et al., 2005). Lesmeister et al. (2005) investigated levels of molasses in MR and found that a level above 12% had a negative correlation with starter DMI. Calf starters containing more than 12% molasses is not recommended.

Calf Growth and Feeding

Milk replacer (MR) is a viable option for producers as herd size grows and nutritional science of MR is developed. The use of milk MR in the United States is about 50% across farms, and an additional 14.4% of farms feeding a combination of MR and saleable or nonsaleable/waste milk (USDA, 2014). There are many different options of feeding MR, depending on what is best for the operation and what the operation is looking for as a response from calves. The two most common MR feeding programs for producers are conventional and intensive feeding. Conventional feeding is typically a MR containing 20 to 22% crude protein (CP) and 15 to 20% fat and contain 12.5 % solids when reconstituted (Raeth-Knight et al., 2009), whereas an intensive feeding program aims to feed more MR DM per day and typically contains a higher CP, as well as offering more solids to the calf.

A simulation done by Kertz and Loften (2013) shows that CP above 20% in MR is beneficial to calves, in that it promotes lean tissue growth as well as additional energy to be used as fat. Benefits of an intensified feeding strategy were seen in the recent study done by de Paula et al. (2017). These benefits can be seen when the MR contains 28% CP and 15-20% fat (Soberon and Van Amburgh, 2012). Added benefits were not seen when the intensified program utilized a moderate protein MR (de Paula et al., 2017), which is in line with both the simulation done by Kertz and Loften and the finding the meta-analysis done by Soberon and Van Amburgh (2013). The concern regarding starter intake being diminished in an intensified feeding program is common. The literature shows that although starter intake is diminished in such programs, and more days are needed to reach sufficient starter intake prior to weaning, after weaning calves increased their starter intake, and BW tends to be similar (de Paula et al., 2017).

The objective of conventional feeding is to stimulate starter intake (de Paula et al., 2017). With liquid intake being restricted in the diet, the calf should ingest more starter to assist with rumen development. A study done by Hill et al. (2016) shows that if MR is fed more than 0.7 kg/d of DMI, postweaning ADG is typically less than calves fed less than the previous stated amount and this could be due to lower preweaning starter intake.

There are benefits to both of these popular feeding systems. It is important for the producer to take into account their objectives and resources. Feeding a conventional system will help with starter intake and rumen development. An intensive program will increase ADG so long as the appropriate % CP is met and that calves are ingesting the sufficient amount of starter to be weaned (de Paula, 2017).

Cutting back on the amount of MR fed just prior to weaning causes a surge in solids consumption, this is called the “step down” system (Khan et al., 2007). This system can encourage calves on an intensive feeding program to increase their solids consumption to promote crucial rumen development.

Early Life Calf Growth and First Lactation

Various studies have been done that look into the effects of early life calf growth and its relationship to production later in life (Chester-Jones et al., 2017; Gelsinger et al., 2016). A recent meta-analysis (Gelsinger et at., 2016) indicated that 305-d milk, protein, and fat yields in first lactation had a positive relationship with preweaning average daily gain. This analysis also showed that faster growing calves, 0.5 to 0.9 kg/d, had a positive effect on first their lactation production. Chester-Jones et al. (2017) also looked into the relationship between early-life growth, intake, and birth season and the first lactation performance. The meta-analysis showed that BW and ADG at 6 and 8 wk were positively related to first lactation milk and components. The regression done for this study estimated that for every 1 kg of 6-wk ADG there was a 544 kg increase in 305-d milk.

The regression also estimated that for every 1 kg of 8-wk ADG, there was a 579 kg increase in 305-d milk. Variance was high in this analysis, suggesting that there are additional factors associated with first lactation performance.

First-lactation milk yield has been shown to be positively correlated with preweaning ADG and weaning weight (Soberon et al., 2012). This study done by Soberon et al., 2012, showed that when looking at the postweaning period, every kilogram increase in ADG from weaning to breeding, heifers produced 8,200 kg of milk. This study also looked into the preweaning diets of these calves and the effects of early life nutritional intake had later in life during first lactation. It appeared that the higher the nutrient intake preweaning, allowed for a positive relationship of nutrient intake postweaning.

Traditional practices indicate that early weaning or restricting milk replacer or milk to increase starter intake is advantageous to producers (Anderson et al., 1987; Klein et al. 1987). Dry feed consumption is beneficial for the preweaned calf (Anderson et al., 1987). However, a recent study done by Soberon et al., 2012, investigated the importance of liquid milk in the diet of growing calf. The observation was that nutrition has the capability to manipulate early life programming immediately following birth through at least 5 wk and must be in the form of liquid feed to have a positive effect on performance throughout the calf's life. Studies show that early life liquid feed and increased nutrient intake can promote mammary cell growth (Brown et al., 2005, Meyer et al., 2006).

Studies that have investigated the early-life of the calf and first lactation production have shown that nutrition plays a role in growth which can be positively correlated with first-lactation performance (Chester-Jones et al., 2017; Gelsinger et al., 2016, Soberon et al., 2012). Chester-Jones et al. (2017) and Gelsinger et al., also noted that vaiance is high with these estimates, suggesting additional that factors may also have a role in first lactation performance.

Energy and Protein

It is advantageous for producers to reduce age at first calving and maximize lean tissue growth. The NRC (2001) provides guidelines to reduce age at first calving and maximize future milk production. Calves use ME from milk or milk replacer with efficiencies of 86%, and that number does not change with starter consumption (NRC, 2001). The estimated ME requirement for a 50 kg calf gaining 400 g/d is around 3.00 Mcal/d according to the NRC (2001). This number is considerably less than estimates published in the previous NRC in 1989 of 5.90 Mcal/d.

Increased energy intake by calves is desired to increase growth or the maintenance of normal growth in cold weather (Kuehn et al., 1994). Kuehn et al. (1994) found that adding fat to MR or starter may be helpful in periods of stress or cold weather, but can actually be detrimental for calves in mild or less stressful conditions. The investigators found that excess fat in MR depressed DMI. Serjrsen and Purup (1997) also found that feeding excess fat can lead to more detriments as well. They suggest is that high energy diets have been shown to impair mammary developments, due to excessive fat deposition.

A calf can achieve a younger age of puberty and first calving by increased energy and protein without causing excessive fat deposition (Brown et al., 2005). Brown et al. (2005) found that a high protein (30.3% CP) and lower fat diet (15.9% CF) along with a high protein starter (25% CP) was the most beneficial diet that allowed for optimal growth without excessive fat deposition. Calves that consumed higher amounts of energy and protein had higher gains and higher feed efficiencies from 2 to 8 wk and 8 to 14 wk as well.

The ratio of CP-to-energy contained in the MR being fed to calves is crucial for optimal growth and performance. Hill et al. (2009) conducted multiple trials that offer insight into protein and energy ratios. The authors first investigated CP content (27%, 25%, or 23%) while holding lysine (Lys) and methionine (Met) at a constant concentration. The authors found that as CP declined, so did preweaning ADG and feed efficiency.

Hill et al. (2009) also investigated CP-to-energy ratios for two different amounts of MR fed to calves. The authors found that at the low ME intake, DM from a MR containing 25% CP, 17% fat, 2.26% Lys, and 0.68% Met, fed at 0.545 kg/d provided 3.26 Mcal/d of ME. 51.5 g of CP/Mcal of ME was the ideal ratio to increase ADG with this feeding regimen.

Looking into a higher ME intake, DM from a MR containing 27% CP, 17% fat, 2.41% Lysine, and 0.75% Met at a rate of 0.645 kg/d, the authors found this provided 3.71 Mcal/d. This feeding regimen offered a ratio of 55.0 g CP/Mcal of ME, the ideal ratio to achieve optimal ADG.

The NRC 2001 Edition

Nutrient Requirements of Dairy Cattle (2001) is a widely used reference that reflects changes in the dairy industry regarding nutrient requirements for individual animals. The NRC (2001) also provides guidance on feeding, ingredient utilization and formulation of diets fed to both the growing calf as well as the mature cow. These guidelines are used to maximize the animal's health and efficiency and growth.

The NRC was last published reflecting the dairy industry in 2001. Since then new information has been acquired through research regarding calf and heifer diets (Hill et al., 2013). A review done by Hill et al. (2013) found the 2001 edition of the Dairy NRC does not outline amino acid requirements. Since the NRC's publication in 2001, there have been studies done that reference amino acids, such as lysine and methionine ratios, and how they play a role in feed efficiency and growth (Castro et al., 2016; Hill et al., 2008).

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Interpretive Summary

Relationship between protein and energy consumed from milk replacer and calf starter and first lactation production performance of Holstein dairy cows. Rauba et al. (2017). The objective of this study was to determine the relationship between protein and energy consumed from milk replacer and starter and first lactation performance of Holstein dairy cows. Data from 3,627 Holstein dairy calves were analyzed from three Minnesota commercial dairies. This study found a positive correlation between energy and protein consumed in early life and milk production in first lactation.

Relationship between protein and energy consumed from milk replacer and calf starter and first-lactation production of Holstein dairy cows.

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SUMMARY

The objective of the study was to determine relationships between protein and energy consumed from milk replacer and calf starter and first lactation performance of Holstein dairy cows. Data were collected from 3,627 Holstein animals from birth year of 2004 through 2014. Calves were received from 3 commercial dairy farms in Minnesota and assigned to 45 different calf research trials at the University of Minnesota Southern Research and Outreach Center, Waseca, MN from 3 to 195 d. A majority of calves were fed a 20% CP and a 20% fat milk replacer at a rate of 0.57 kg/calf per day. Milk replacer (MR) metabolizable energy (ME), starter ME, MR protein intake, and starter protein intake consumed from 0-8 weeks were (mean ± SD): 102.7 ± 13.3 Mcal/kg, 151.9 ± 41.4 Mcal/kg, 4.8 ± 1.0 kg, and 9.5 ± 2.6 kg, respectively. The MR ME, starter ME, MR protein intake, and starter protein intake consumed from first lactation production data were analyzed for the 3,627 cows, which included 305-d milk, average across all farm was about 10,946 kg of milk, 404 kg fat, and 337 kg protein.

Separate mixed model analyses were conducted with SAS (SAS Inst. Inc, Cary, NC) to determine the effect of protein or energy consumed on first lactation production of milk, fat, and protein yield. The 305-d milk and components production were positively affected by early life ME and protein intake. Higher ME and protein intake in the first 8 weeks of life resulted in increased first lactation milk and milk components yield as well. For every 1 kg increase in ME consumed through the first 8 wk of life, there was a 1.80 kg increase in 305-d milk, 0.09 kg increase in 305-d fat, 0.09 kg increase in 305-d protein. Calves born in the fall and winter consumed both more ME and protein than calves born in the spring and summer. Calves in the summer consumed on average 17.45

kg combined protein 0-6 wk of life, 17.16 kg for spring born calves, 19.67 kg for fall born and 19.67 kg for winter born. The same goes for ME consumed 0-6wk; Combined ME for summer born calves 154.99 Mcal/kg, 155.33 Mcal/kg for spring born, 164.13 Mcal/kg for fall born, and 169.62 Mcal/kg for winter born. The majority of calves were weaned at 6 wk, this caused a more significant starter effect in birth season and protein and ME consumption from starter from 0-8 wk of life. There was a considerable amount of variation seen around these estimates, suggesting other factors affect first lactation production.

Key words: milk replacer, starter, first lactation production, early-life growth.

INTRODUCTION

The health and nutrition of the pre-weaned calf has been of increasing interest to both nutritionists and dairy farmers alike. What the calf consumes and how it is utilized in its body can translate to a healthier and faster growing calf, which may lead to a more productive animal through breeding and first lactation. Optimizing calf growth and health can be done in many ways, such as housing, hygiene, colostrum management, and nutrition management.

First-lactation milk yield has been shown to be positively correlated with pre-weaning ADG and weaning weight (Soberon et al., 2012). The study showed that the higher the nutrient intake pre-weaning, the more nutrient intake the heifer would have post-weaning. They also found that for every kg increase in ADG from weaning to breeding, first-lactation cows can produce an additional 849 kg of milk. Studies show that early life liquid feed and increased nutrient intake can promote mammary cell growth (Brown et al., 2005, Meyer et al., 2006) which may account for the correlation seen between pre-weaning nutrition and feeding and subsequent higher milk production.

Various studies have analyzed early life calf growth and it relationship to first lactation production (Chester-Jones et al., 2017; Gelsinger et al., 2016). Gelsinger et al. (2016) showed that pre-weaned calf nutrition played a role in 305-d milk and component yield. As previously mentioned, other management practices are also crucial for calf development. They also emphasized that pre-weaned calf nutrition from both milk replacer (MR) and starter can enhance the effects observed when a producer has excellent management for housing, colostrum administration, and hygiene. Finally, Gelsinger et al. (2016) reported that growth rate had little effect on first lactation between 0.3 and 0.5

kg/d, but the effects increased as growth rate increased from 0.5 kg/d to 0.9 kg/d. Chester-Jones et al. (2017) found that BW and ADG at 6 and 8 wk positively influenced first-lactation production. For every 1 kg of 6-wk ADG 305-d production increased by 544 kg during first lactation, and for every 1 kg of 8-wk ADG, milk production increased by 579 kg during first lactation.

Feeding higher protein and fat is something many producers and nutritionists are interested in for calf feeding programs. A calf's diet that is higher in fat and protein is both common and recommended for cold weather (Jaster et. al, 1992), as well as to decrease the age of puberty, increase mammary development (Meyer et al., 2006) and increase average daily gain (Brown et al., 2005; Kuehn et al., 1994; Piantoni et al., 2012). In cold weather, added fat is utilized in the diet to maintain the calf's energy requirements and increase or maintain growth. Jaster et al. (1992) found that added fat can increase body weight in colder months. Brown et al. (2005) found that a diet of high protein (30.3% CP) and lower fat (15.9% CF) along with a high protein starter (25% CP) was the most beneficial for growing calves without causing excess fattening that may lead to mammary gland development impairment (Sejersen, 1994). Piantoni et al. (2012) states that feeding calves twice the nutrient intake found in conventional MR may be sufficient to enhance mammary development through mRNA expression, however further investigation is necessary to conclude how this affects first-lactation production.

Based on previous research determining the relationship between ADG and first-lactation production in Holstein cows, we hypothesized that that improvements in ME and protein intake in the first 8 wk of life would be associated with increased first-lactation production. Therefore, the objective of this study was to determine relationships between protein and energy consumed from MR and starter and first lactation performance of Holstein dairy cows.

MATERIALS AND METHODS

Calf Management and Data Collection

Data were collected from birth yr of 2004 to 2014 for 3,627 Holstein cows. Calves were from three commercial dairy farms in Minnesota which all together represent over 2,000 dairy cows. Between 2 to 5 days of age, heifer calves were picked up twice weekly and taken to the University of Minnesota Southern Research and Outreach Center (SROC). Blood samples were taken on d 1 via jugular venipuncture and analyzed for total serum protein concentration using a refractometer (Spartan Refractometer, Model A 300 CL, Spartan, Tokyo, Japan). Average serum protein across all farms was 5.5 g/dl (n = 3,627). For the 3 farms, serum protein was: Farm A, 5.5 g/dl (n = 1,392), Farm B, 5.4 g/dl (n = 1,338), and Farm C, 5.6 g/dl (n = 897). Calves were then assigned to 45 different studies at SROC.

Each study occurred at the SROC Calf Heifer and Research Facility in individual pens (2.3 x 1.2 m) inside 2 curtain side-wall, naturally ventilated (9 x 61 m) barns. The barns contained 2 rooms that had approximately 40 calves per room. In the winter, the pens were bedded with straw. In the summer, the pens were bedded with wood shavings. All the animals and procedures were approved by the University of Minnesota Institutional Animal Care and Usage Committee (Animal Subjects Code #1410B54891).

A majority of calves (92%) were fed a milk replacer of all milk protein that contained 20% crude protein (CP) and 20% fat, and 8% of the calves were fed a partial alternative protein source milk replacer that contained 20% crude protein (CP) and 20%

fat. The partial alternative MR contained protein from either soy, wheat, plasma, or a mixture of both wheat and plasma sources at varying percentages of the total MR protein. Ninety percent of the 45 trials utilized a feeding rate of 0.57 kg/calf daily. Ten percent of the studies did not feed a conventional 20:20 milk replacer or feed a 0.57 kg/calf daily feeding rate. The majority of calves were weaned at 6 wk of age. Data collected on calves included daily milk replacer intake, starter intake, growth (body weights and hip height), calf health, and feed efficiency. Body weights were taken every 2 weeks until d 56.

At 2 mo of age, heifers moved from the nursery and put into group housing pens (6.4 x 2.7 m) with 6 to 8 other heifers for 112 d. Heifers were offered the same starter as they were fed prior to weaning for a few days then limit-fed a 16% crude protein (as-fed) grain mix at the rate of 2.27 to 2.73 kg/heifer per day. Hay and water were offered ad libitum during this time. Heifers remained in these group pens until 6 to 7 mo, from which they were then transferred to the next phase growers and returned to their original dairy farm prior to calving.

The calves were from three commercial dairies: Farm A had 1,392 calves, Farm B had 1,338 calves, and Farm C had 897 calves. Metabolizable energy (ME) and protein consumed were calculated for each individual calf for 6 wk and 8 wk. The NRC (2001) equations were used to calculate ME. Starter ME average of 3.28 Mcal/kg was used from the NRC (2001). Protein consumed was calculated from the protein content of the milk replacer and calf starter.

$$\text{ME (Mcal)} = 0.1\ LW^{0.75} + (0.84\ LW^{0.355} \times LWG^{1.2})$$

ME of MR (Mcal/kg) = [0.057 × CP (%) + 0.092 × Fat (%) + 0.0395 × Lactose (%)] × 0.9312

Statistical Analysis

Separate mixed model analysis were conducted with PROC MIXED of SAS (SAS Inst. Inc, Cary, NC) to determine the effect of actual ME consumed from milk replacer and starter and actual protein consumed from milk replacer and starter and the relationship with first lactation production of milk, fat, and protein yield. Dependent variables were 305-d milk production, 305-d fat, and 305-d protein production. Independent variables were birth season (spring, summer, autumn, winter), year of birth, MR protein, starter protein and combined protein consumed from 0-6 wk and 0-8 wk. As well as MR, starter, and combined ME consumed from 0-6 wk and 0-8 wk. Calf trial was a random effect.

RESULTS AND DISCUSSION

Table 1 shows ADG, DMI, ME intake, protein intake, and first-lactation yield parameters (mean; SD) of the three individual farms and across all the farms. For all farms, 6 wk MR protein, starter protein, and combined protein intake were: 4.7 ±1.0 kg, 3.6 ± 1.5 kg, and 18.3 ± 5.2 kg, respectively. For all farms, 8 wk MR protein, starter protein, and combined protein were: 4.8 ± 1.0 kg, 9.5 ± 2.6 kg, and 24.2 ± 6.2 kg, respectively. For all farms, 6 wk MR ME, starter ME, and combined ME intake were: 102.2 ± 12.6 Mcal/kg, 58.2 ± 24.3 Mcal/kg, and 160.4 ± 26.4 Mcal/kg, respectively. For all farms, 8 wk MR ME, starter ME, and combined ME intake were: 102.7 ±13.3 Mcal/kg, 151.9 ± 41.2 Mcal/kg, and 254.6 ± 43.3 Mcal/kg, respectively. First-lactation milk yield, protein yield, and fat yield across all farms were: 10,977 ± 1,753 kg, 338 ± 52 kg, and 405 ± 73 kg, respectively. According to our analysis, calves consumed slightly less ME and protein than what is recommended in the NRC (2001), suggesting that the calves may have had better feed conversion than what is predicted in the NRC (2001). All calves were managed the same so there was not much difference between Farms A, B, and C in regards to growth rates (Table 1).

Early life protein consumption vs. first lactation performance

Calf MR and starter protein intake at 6 wk were analyzed to predict first-lactation 305-d milk yield (Table 2). Combined protein (both MR and starter) consumed was significant leaning towards starter protein intake. For every kg increase consumed of combined protein there was a 13.21 kg increase in milk production (P<0.05; Table 2). Starter protein intake did show a trend, (P=0.12), and for every kg increase in starter protein consumed there was a 31.52 kg increase in milk production.

However, when plotting 305-milk vs. combined protein intake from the first 6 weeks, we saw that there is variance around the estimate (Figure 1). And despite the high level of significance seen with combined protein intake, it is difficult to be confident with the prediction because of the high variance seen in around the estimate (Figure 1).

Increasing combined protein consumption from 0-6 wk and 0-8 wk increased first-lactation milk and components. (P<0.05; Table 2). For every kg increase in combined protein consumed, there was a 11.32 kg increase in milk production. For the first 8 weeks of life, we saw a stronger trend towards starter protein consumption (P=0.06), for every kg increase in starter consumed, there was 22.92 kg increase in milk production. Similar to the analysis done for 6 wk, through 8 wk of life there was high level significance for combined protein intake and first-lactation milk production, but as we saw with 6 wk as well, there was high variance around the estimate (Figure 3). Suggesting that other factors also play a role in first-lactation milk and components in addition to our analysis of 0-8 wk protein consumption.

Chester-Jones et al. (2017) concluded that calf BW and ADG at 6 and 8 wk had significant positive effects on 305-day first lactation milk, fat, and protein yield. The researchers saw that every kg of 6 wk ADG was associated with 544 kg more first-lactation 305-d milk and every kg of 8 wk ADG yielded 579 kg more first-lactation 305-d milk. But like our analysis, this study found high variation around the estimates. Intake of calf starter DM at 8 wk improved first-lactation performance. This is similar to the trend we saw when analyzing the actual amount of protein consumed from starter for calves involved in these trials. Combined protein intake had a significant effect on first-lactation 305-d milk with a trend of significance leaning towards starter (Table 2).

Early life metabolizable energy consumption and first lactation performance

Metabolizable energy was analyzed at 6 and 8 wk to predict first-lacation 305-d milk yield similarly to protein intake. The trends seen were similar as well to protein intake. 6 wk ME was significant for combined ME (P<0.05; Table 3). For every Mcal/kg increase in ME consumed there was a 2.95 kg increase in first-lactation 305-d milk production. Again, we saw a trend towards starter ME consumed in this analysis (P=0.12). For every Mcal/kg increase in combined ME, there was a 1.80 kg increase in first-lactation 305-d milk production. Through 8 wk we saw the trend towards starter ME become more significant (P=0.06; Table 3). Despite the significance seen, there was high variance around the estimate (Figures 2 and 4).

Gelsinger et al. (2016) also reported that pre-weaned calf nutrition played a role in 305-d milk, protein, and fat yields in first-lactation production, which also supports the conclusions stated by Chester-Jones et al. (2017) and Soberon et al. (2012). Pre-weaning nutrition obviously plays a role seen later in life, as observed in our study and previous studies. In many of the studies variation is high around the estimates, but pre-weaning nutrition can be used to enhance good management practices.

Birth season vs early life protein and metabolizable energy consumption and first lactation performance

Looking into the effects of birth season on 6 and 8 wk MR and starter protein (kg) and ME (Mcal/kg) and first lactation 305-d milk yield, we saw that calves born in the fall and winter consumed more (P=0.05; Table 4). However, summer born calves produced more in first-lactation. Calves in the summer consumed on average 17.45 kg combined protein 0-6 wk of life, 17.16 kg for spring born calves, 19.67 kg for fall born and 19.67kg for winter born. Combined ME for summer born calves 154.99 Mcal/kg, 155.33 Mcal/kg for spring born, 164.13 Mcal/kg for fall born, and 169.62 Mcal/kg for winter born.

Kuehn et al. (1994) stated that increased energy intake by calves is desired to increase growth or the maintenance of growth in cold weather. This is why more consumption of protein and ME is seen in calves in the winter and fall. They require more energy for maintenance in harsher environments. Our results compliment what Soberon et al. (2012) found with their summer calves, that the summer calves produced 556 kg more first-lactation milk than calves born in the winter. The calves in our analysis produced about 107 kg more 305-d milk in the summer than in the winter across all three farms.

Our analysis of ME and protein consumed and how that correlates to birth season and its effects on first-lactation production show that both milk replacer and starter are important components in the pre-weaned calf diet. Both combined protein and combined ME are significant when it comes to increasing 305-d milk and components (Table 2 and 3). Season plays a role in how much protein and ME is consumed (Table 4), suggesting that supplementing calf diets with more energy and protein may be beneficial for the calf during colder weather to maintain its energy requirements. When planning a feeding regimen for a calf, many factors come into play, our research suggests that both MR and starter fed can have an effect on the calf through first-lactation production.

CONCLUSIONS

A combination of both early life MR and starter ME intake positively affected 305-d milk as well as a combination of both early like MR and starter protein. Calves born in the fall and winter consumed more protein and ME, but calves in the summer produced more first lactation 305-d milk. Suggesting that calves born in the fall and winter require more energy for daily maintenance, than calves born in warmer months. Variance was high in all estimates, suggesting additional factors affect first lactation milk production. Our research shows that calves were consuming less than recommended NRC (2001) values. However, vanriance was high for our estimates, hence we cannot conclude with confidence that the calves analyzed in our dataset were more efficient at feed conversion than what the NRC (2001) states protein and ME requirements to be. Further investigation is needed to compare current NRC (2001) requirements to what calves are consuming and how effects first-lactation performance.

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Table 1. Holstein calf milk replacer, starter intake, BW, ADG, and first-lactation production for all 3 Minnesota herds.

	Farm A (n =1,392)		Farm B (n =1,338)		Farm C (n =897)		All Farms (n =3,627)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
6-wk Milk replacer intake (kg)	21.8	2.5	22.1	2.8	21.9	2.7	22.0	2.7
6-wk Starter intake (kg)	17.3	7.6	17.9	7.3	18.3	7.4	17.8	7.4
6-wk Milk replacer protein intake (kg)	4.7	0.9	4.8	1.0	4.7	1.0	4.7	1.0
6-wk Starter protein intake (kg)	3.6	1.6	3.7	1.5	3.8	1.5	3.6	1.5
6-wk Milk replacer ME intake Mcal/kg)	101.7	11.8	103.0	13.2	101.8	12.6	102.2	12.6
6-wk Starter ME intake (Mcal/kg)	56.8	24.8	58.6	23.9	59.9	24.2	58.2	24.3
6-wk Combined ME intake (Mcal/kg)	158.5	26.7	161.6	26.3	161.8	25.8	160.4	26.4
6-wk Combined Protein Intake (kg)	8.3	1.8	8.5	1.7	8.5	1.7	8.4	1.8
6-wk ADG (kg/d)	0.5	0.1	0.6	0.1	0.6	0.1	0.6	0.1
8-wk Milk replacer intake (kg)	22.0	2.7	22.2	3.0	22.0	2.9	22.1	2.9
8-wk Starter intake (kg)	45.2	12.7	46.9	12.6	47.2	12.4	46.3	12.6
8-wk Milk replacer protein intake (kg)	4.7	1.0	4.8	1.1	4.8	1.1	4.8	1.0
8-wk Starter protein intake (kg)	9.3	2.6	9.6	2.6	9.7	2.6	9.5	2.6
8-wk Milk replacer ME intake Mcal/kg)	102.3	12.6	103.4	13.9	102.3	13.6	102.7	13.3
8-wk Starter ME intake (Mcal/kg)	148.1	41.7	153.9	41.3	154.7	40.5	151.9	41.4
8-wk Combined ME intake (Mcal/kg)	250.4	43.4	257.3	43.7	257.0	41.9	254.6	43.3
8-wk Combined Protein Intake (kg)	14.0	2.8	14.5	2.8	14.5	2.8	14.3	2.8
8-wk ADG (kg/d)	0.6	0.1	0.7	0.1	0.7	0.1	0.7	0.1
305-d milk (kg)	10,408.5	1,725.5	11,362.7	1,765.5	11,157.9	1,462.6	10,945.9	1,733.8
305-protein (kg)	321.3	48.6	356.5	54.3	331.5	40.1	336.8	51.3
305-fat (kg)	370.5	61.3	440.8	76.5	402.4	56.8	404.4	73.0

Table 2. Calf Milk Replacer and Starter Protein Intake (kg) at 6 wk and 8 wk to predict first-lactation 305-d milk yield (n=3,627).

		Milk Replacer Protein (kg)			Starter Protein (kg)			Combined Protein (kg)		
Variable	Week	Estimate	SE	P-value	Estimate	SE	P-value	Estimate	SE	P-value
305-d milk	6	38.81	32.98	0.2395	31.52	20.35	0.1215	39.17	18.63	0.0356
305-d fat	6	1.25	1.55	0.4209	1.98	0.79	0.0116	2.04	0.74	0.0060
305-d protein	6	0.73	1.04	0.4861	1.94	0.59	0.0010	1.87	0.55	0.0006
Variable	Week									
305-d milk	8	34.61	31.28	0.2686	22.92	12.06	0.0573	26.04	11.59	0.0247
305-d fat	8	1.40	1.45	0.3352	1.31	0.46	0.0047	1.38	0.45	0.0023
305-d protein	8	0.69	0.98	0.4831	1.32	0.35	0.0001	1.33	0.34	<0.0001

Table 3. Calf Milk Replacer and Starter ME Intake (Mcal/kg) at 6 and 8 wk to predict first-lactation 305-d milk yield (n=3,627).

		Milk Replacer ME (Mcal/kg)			Starter ME (Mcal/kg)			Combined ME (Mcal/kg)		
Variable	Week	Estimate	SE	P-value	Estimate	SE	P-value	Estimate	SE	P-value
305-d milk	6	4.31	2.52	0.0873	1.99	1.27	0.1185	2.95	1.24	0.0173
305-d fat	6	0.15	0.12	0.2049	0.12	0.05	0.0135	0.14	0.05	0.0032
305-d protein	6	0.11	0.08	0.1803	0.12	0.04	0.0009	0.14	0.04	0.0001
Variable	Week									
305-d milk	8	3.63	2.35	0.1225	1.43	0.76	0.0582	1.80	0.75	0.0167
305-d fat	8	0.15	0.10	0.1375	0.08	0.03	0.0062	0.09	0.03	0.0017
305-d protein	8	0.09	0.07	0.1979	0.08	0.02	0.0001	0.09	0.02	<0.0001

Table 4. Effect of birth season on 6 wk MR and Starter Protein (kg) and ME (Mcal/kg) and first-lactation 305-d milk yield (n=3,627).

	Birth season	P-			
Variable	value	Spring	Summer	Fall	Winter
6 wk MR Protein Intake (kg)	0.0519	4.67^{ab}	4.67^{ab}	4.59^{b}	4.71^{a}
6 wk Starter Protein Intake (kg)	<0.0001	3.37^{b}	3.37^{b}	4.03^{a}	4.21^{a}
6 wk MR ME Intake (Mcal/kg)	0.0011	101.19^{b}	101.02^{b}	99.91^{b}	102.51^{a}
6 wk Starter ME Intake (Mcal/kg)	<0.0001	53.72^{b}	53.66^{b}	64.20^{a}	67.00^{a}
6 wk Combined Protein Intake (kg)	<0.0001	8.07^{c}	8.09^{c}	8.61^{b}	8.90^{a}
6 wk Combined ME Intake (Mcal/kg)	<0.0001	155.33^{c}	154.99^{c}	164.13^{b}	169.62^{a}
8 wk MR Protein Intake (kg)	0.0567	4.70^{ab}	4.70^{a}	4.59^{b}	4.73^{a}
8 wk Starter Protein Intake (kg)	<0.0001	9.01^{b}	9.10^{b}	10.23^{a}	10.23^{a}
8 wk MR ME Intake (Mcal/kg)	0.0025	101.83^{a}	101.50^{a}	100.06^{b}	102.88^{a}
8 wk Starter ME Intake (Mcal/kg)	<0.0001	143.55^{b}	144.87^{b}	162.85^{a}	162.83^{a}
8 wk Combined Protein Intake (kg)	<0.0001	13.75^{b}	13.85^{b}	14.81^{a}	14.92^{a}
8 wk Combined ME Intake (Mcal/kg)	<0.0001	245.88^{b}	246.75^{b}	262.87^{a}	265.78^{a}
305-d milk (kg)	0.0734	10,938.83^{ab}	11,041.99^{a}	10,946.66^{ab}	10,831.45^{b}
305-d fat (kg)	0.0026	401.74^{bc}	408.31^{ab}	411.21^{a}	396.31^{c}
305-d protein (kg)	0.0227	333.70^{bc}	338.36^{a}	338.32^{ab}	331.57^{c}

^{abc} Values in the same row with different superscripts are different (*P* < 0.05)

0

Figure 1. Scatter Plot of 305-d Milk and Combined Protein Consumption 0-6 wk.

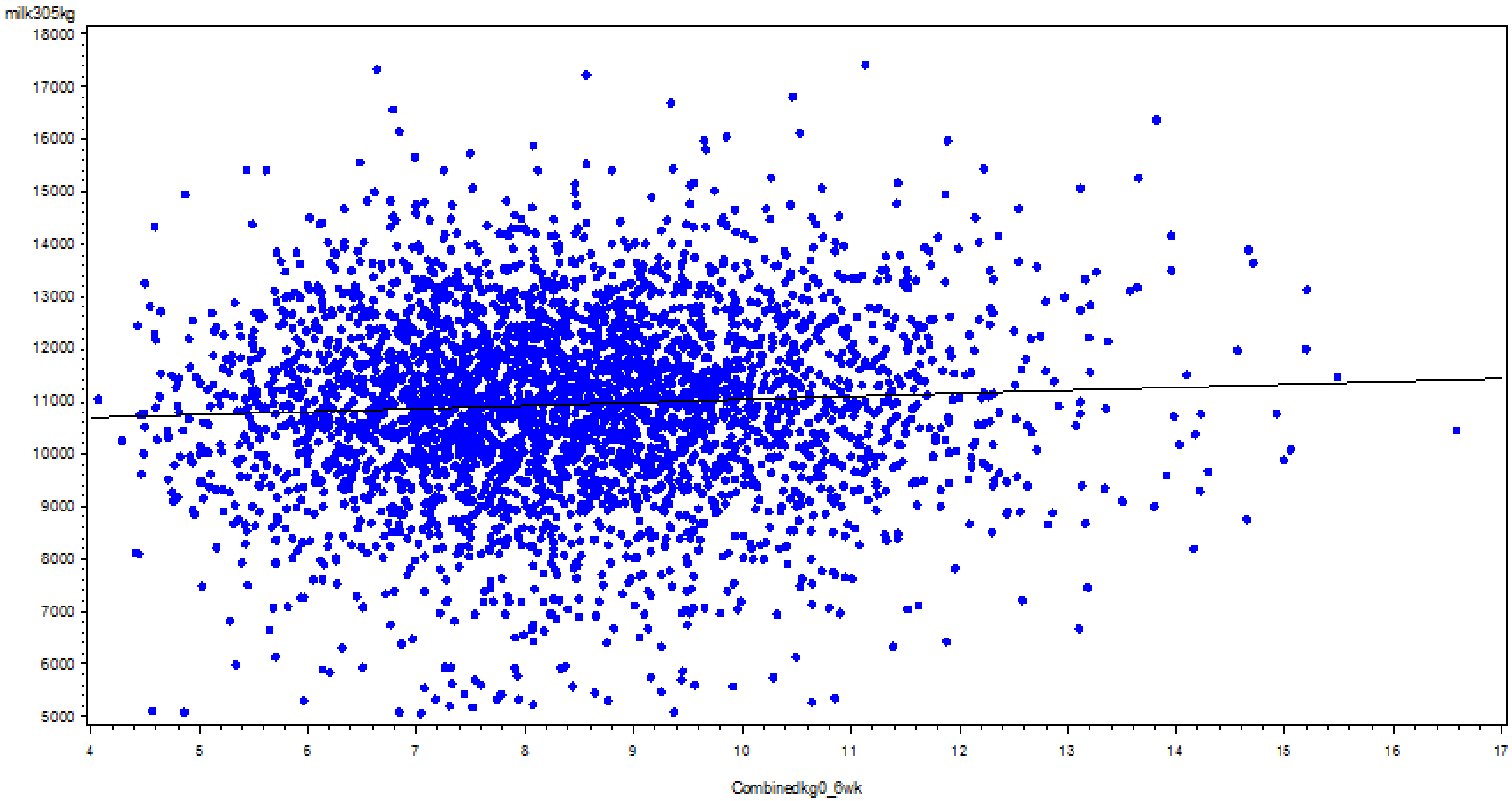


Figure 2. Scatter Plot of 305-d Milk and Combined ME Consumption 0-6 wk.

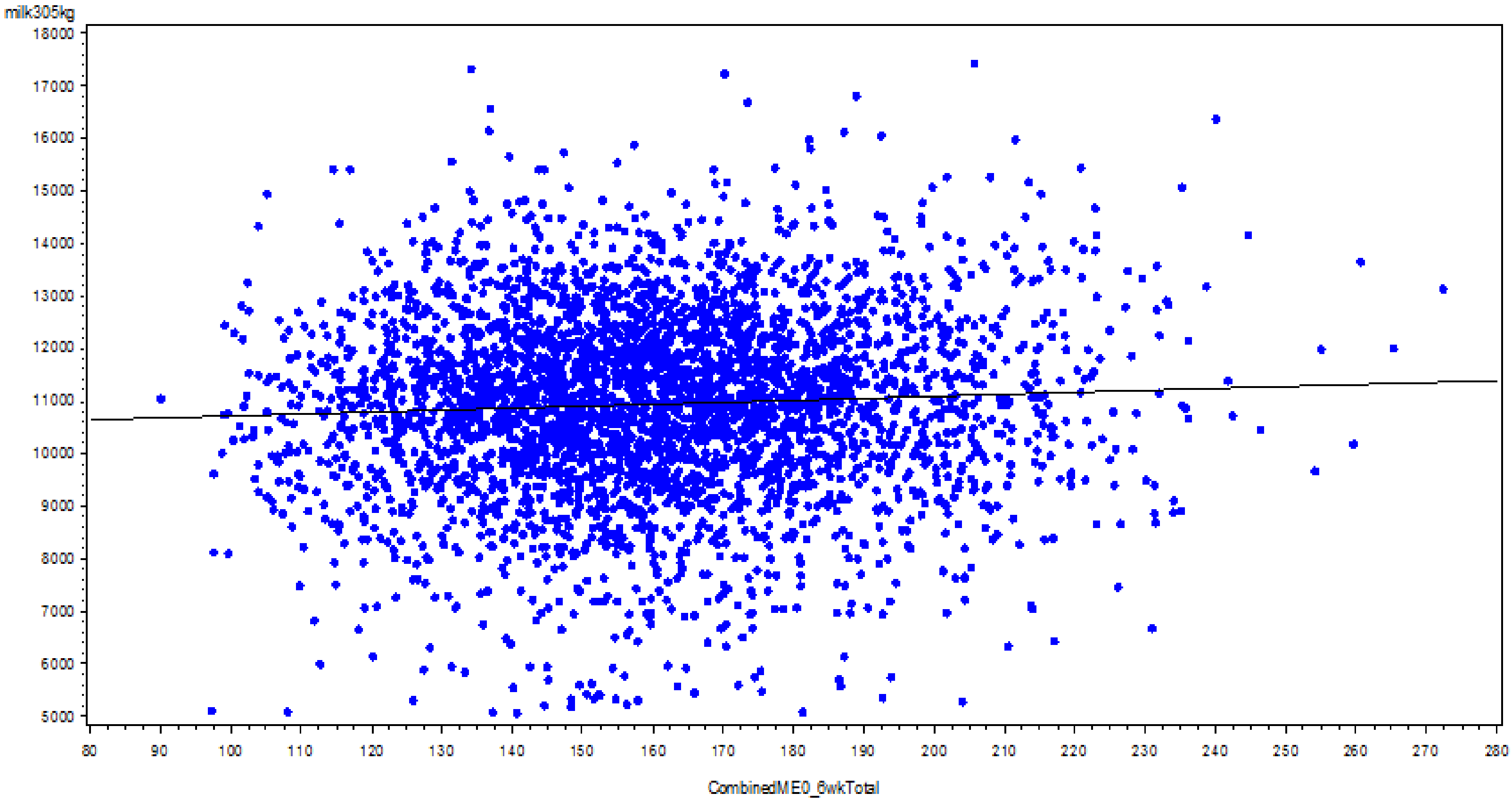


Figure 3. Scatter Plot of 305-d Milk and Combined Protein Consumption 0-8 wk.

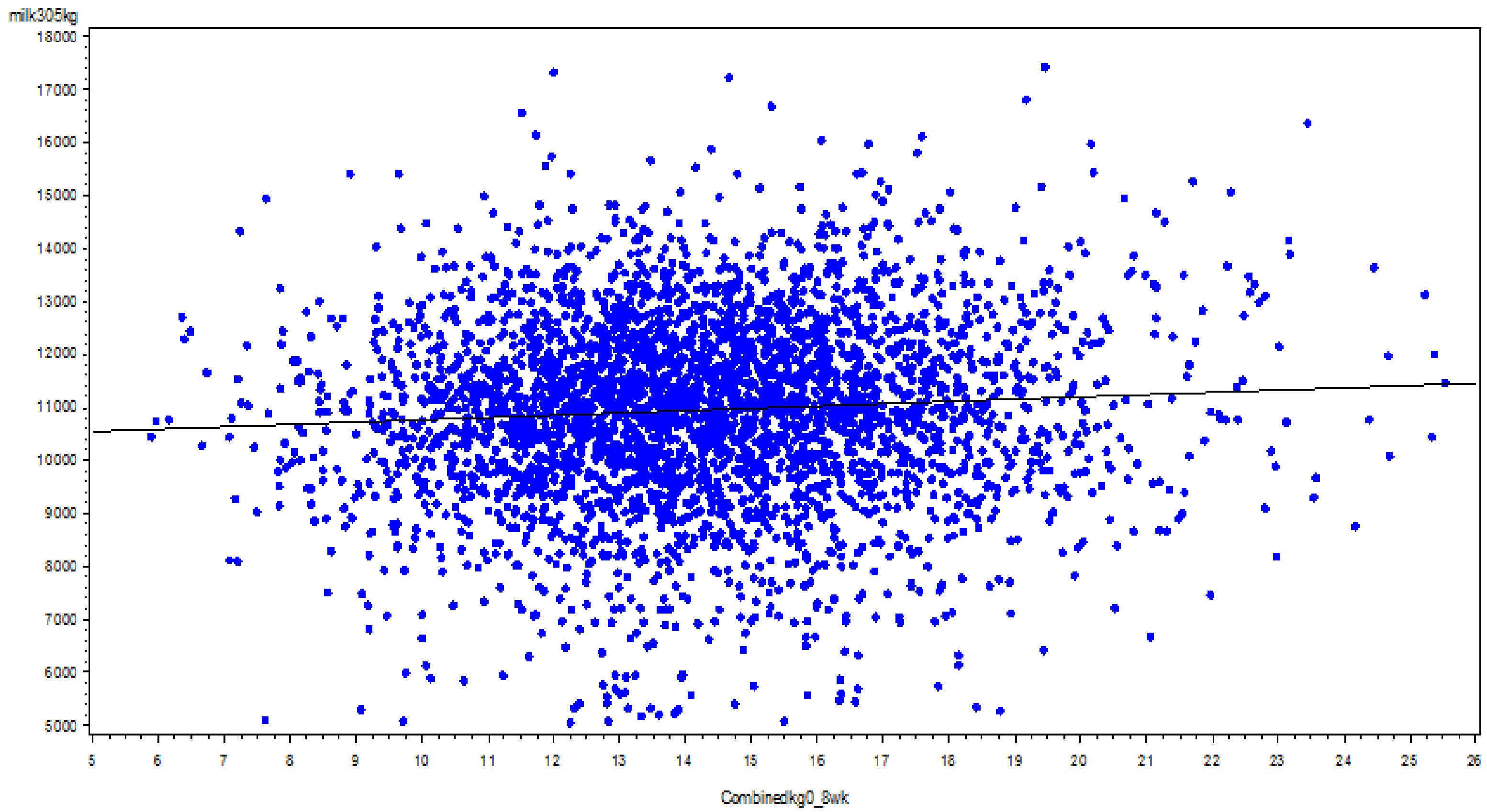
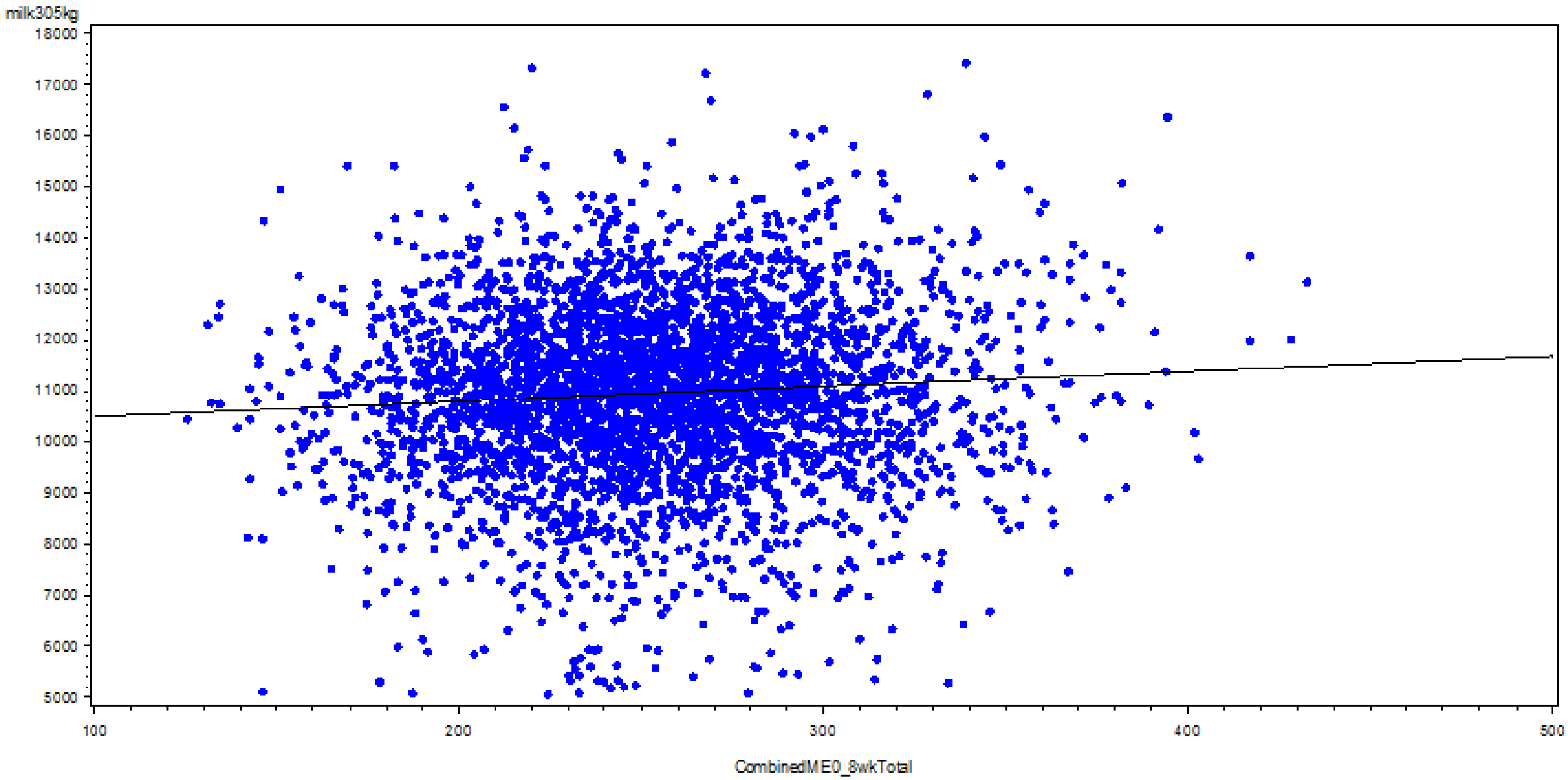


Figure 4. Scatter Plot of 305-d Milk and Combined ME Consumption 0-8 wk.



Interpretive Summary

Relationships between protein and energy consumed from milk replacer and starter and growth for Holstein dairy calves. Rauba et al. (2017). The objective of this study was to determine relationships between protein and energy consumed from milk replacer and starter and calf growth for Holstein dairy calves. Data were collected from 4,534 Holstein animals to determine if early life protein and energy intake were related to calf growth. This study found that there is a positive correlation between energy and protein consumed in early life and calf growth.

Early Life Protein and Energy Intake and Calf Growth Performance

Relationships between protein and energy consumed from milk replacer and starter and growth for Holstein dairy calves.

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SUMMARY

The objective was to determine relationships between protein and energy consumed from milk replacer and starter and calf growth for Holstein dairy calves. Data were collected from 4,534 Holstein animals from birth year of 2004 through 2014. Calves were received from 3 commercial dairy farms and assigned to 45 different calf research trials at the University of Minnesota Southern Research and Outreach Center from 3 to 195 d. Calves were returned to their farms upon completion of the trial. A majority of calves were fed a 20% CP and a 20% fat milk replacer (MR) at a rate of .57 kg/calf per day. Milk replacer ME, starter ME, milk replacer protein intake, and starter intake consumed from 0-8 weeks were (mean ± SD): 102.7 ± 13.2 Mcal/kg, 151.0 ± 42.2 Mcal/kg, 4.8 ± 1.0 kg, and 9.5 ± 2.7 kg, respectively. Separate mixed model analysis were conducted with SAS to determine the effect of actual ME consumed from both MR and starter and actual protein consumed from both ME and starter and average daily gain (ADG) of the calves. Calves that had higher ADG consumed significantly more protein and ME. The calves that were slower growing showed no significant difference in consumption of protein and ME. The analysis of ADG class also showed that in this case, starter was the main influencer on calf growth. The effect of birth season on 8 wk MR and starter protein and ME intake showed that calves born in the fall and winter consumed more protein and ME from both MR and starter, 23.1 kg and 23.3, respectively. The spring born calves consumed the least amount of protein from both MR and starter, 21.7 kg. Summer born calves consumed 22.4 kg protein. Similarly, calves born in the fall and winter consumed more ME from MR and starter. Calves born in the fall consumed a combined ME of 246.7 Mcal/kg, winter calves consumed 250.0 Mcal/kg, spring calves consumed 241.9 Mcal/kg, and summer calves consumed 239.5 Mcal/kg.

Variance was high among all the estimates, suggesting that additional factors also affect calf growth during the first 8 wk of life.

Key words: milk replacer, starter, metabolizable energy.

INTRODUCTION

The NRC (2001) provides guidelines that allow producers and nutritionists to maximize calf health and lean tissue growth, to allow for a faster growing animal, and a younger age at puberty. Achieving faster growth and ensuring the health of the animal involves many factors including colostrum management, hygiene, and nutrition management. There are many different MR and starter options on the market, many which have undergone research by scientists and nutritionists. With so many options on the market, the producer may find themselves overwhelmed by choice as to what will truly help them achieve greater calf growth and optimize health.

Understanding the relationship between protein and energy required in a growing calf is valuable to achieve optimal growth. Various studies have looked into protein and energy provided in the diet and the relationship with calf growth (de Paula et al., 2017; Hill et al., 2013; Kertz and Loften, 2013). A simulation by Kertz and Loften (2013) shows that a MR containing CP above 20% is beneficial to calves to achieve lean tissue growth. Serjrsen and Purup (1997) found that feeding excess fat can lead to developmental detriments, such as mammary development.

Calves that consume greater amounts of energy and protein have greater gains as well as feed efficiencies from 2 to 8 weeks of life and from 8 to 14 weeks of life in a study conducted by Brown et al. (2005). The investigators also found that to achieve a younger age of puberty, calves can be fed a diet with increased protein and energy, while avoiding any issues associated with excess fattening (Serjrsen and Purup, 1997). Brown et al. (2005) found that a high protein MR (30.3% CP) and lower fat (15.9%) would provide 4.4 Kcal of ME/g of DM, and diminish the risks associated with excess fattening, as well as an increase in parenchymal mass and parenchymal DNA and RNA in mammary glands was seen without an increase in parenchymal fat in calves fed high energy and protein from 2 to 8 wk of life.

The NRC (2001) emphasizes the importance of dietary protein and energy intake for the growth of dairy calves. These guidelines also aim to reduce the age of first calving by maximizing lean tissue growth. Calves use ME from milk or MR with efficiencies of 86% (NRC, 2001). In a review investigating how protein is used by calves by Zanton and Heinrichs (2008), it was found that preweaned calves consumed a highly digestible milk-based diet high in ME and thus were more efficient at depositing N.

The objective of the study herein was to determine relationships between protein and energy consumed from milk replacer and starter and growth of Holstein dairy cows. Our findings can be useful information to industry and producers when they are planning their calf feeding regimen, and to help outline objectives the farm has for calf growth and average daily gain.

MATERIALS AND METHODS

Calf Management and Data Collection

Data were collected from birth yr of 2004 to 2014 for 4,534 Holstein cows. Calves came from three commercial dairy farms which all together represent over 2,000 dairy cows in Minnesota. Between the age of 2 to 5 days, heifer calves were picked up twice weekly and taken to the University of Minnesota Southern Research and Outreach Center (SROC). Blood samples were taken on d 1 via jugular venipuncture and analyzed for total serum protein concentration using a refractometer (Spartan Refractometer, Model A 300 CL, Spartan, Tokyo, Japan). Average serum protein across all farms was

5.5 g/dl (n = 4534). Farm A 5.5 g/dl was (n = 1787), Farm B was 5.4 g/dl (n = 1659) and Farm C was 5.6 g/dl (n = 1088). Calves were then assigned to 45 different studies at SROC.

Each study occurred in the SROC Calf Heifer and Research Facility (CHRF) in individual pens (2.3 x 1.2 m) inside 2 curtain side-wall, naturally ventilated (9 x 61 m) barns. The barns contained 2 rooms that held approximately 40 calves per room. In the winter, the pens were bedded with straw. In the summer, the pens were bedded with wood shavings. All the animals were cared for according to the University of Minnesota Institutional; Animal Care and Usage Committee recommendations (Current Standard Operating Procedures #1410B54891).

Of the 45 studies analyzed, the majority of calves (92%) were fed a milk replacer (MR) of all milk protein that contained 20% crude protein (CP) and 20% fat. Eight percent of the calves were fed a partial alternative protein sources that contained 20% crude protein (CP) and 20% fat. The partial alternative MRs contained protein from either soy, wheat, plasma, or a mixture of both wheat and plasma sources at varying percentages of the total MR protein. Ninety percent of these trials utilized a feeding rate of 0.57 kg/calf daily. About 10% of the studies did not feed a conventional 20:20 milk replacer or feed a 0.57 kg/calf daily feeding rate, such as an accelerated feeding rate regimen, these nutrient levels and varying feeding rates were taken into account when analyzing each calf. The majority of calves were weaned at 6 wk. Many data points were collected in each study including: Feed intake, growth, calf health, feed efficiency, and treatments. Milk replacer and starter intake was recorded daily as well. Body weights were taken every 2 weeks until d 56. Standard practices such as dehorning and vaccinations occurred during this time.

Around the age of 2 mo, heifers moved from the nursery and put into group housing pens (6.4 x 2.7 m) with 6 to 8 other heifers for 112 d. Heifers were offered the same starter as they were fed prior to weaning for a few days then limit-fed a 16% CP (as-fed) grain mix at the rate of 2.27 to 2.73 kg/heifer per day. Hay and water were offered ad libitum during this time. Heifers remained in these group pens until 6 to 7 mo, from which they were then transferred to the next phase growers and returned to their original dairy farm prior to calving.

Animals that were missing data were removed, equaling a total of 36 animals. The calves were sorted into their three commercial dairies; Farm A = 1787 animals, Farm B = 1659 animals, and Farm C = 1088 animals. Each individual calf had their consumption of metabolizable energy (ME) and protein calculated through weaning. Starter ME average of 3.28 Mcal/kg was used from the NRC (2001).

To calculate actual ME consumed NRC (2001) formulas were used:

$\text{ME (Mcal)} = 0.1\ \text{LW}^{0.75} + (0.84\ \text{LW}^{0.355} \times \text{LWG}^{1.2})$

$\text{ME of MR (Mcal/kg)} = [0.057 \times \text{CP (\%)} + 0.092 \times \text{Fat (\%)} + 0.0395 \times \text{Lactose (\%)}] \times 0.9312$

Statistical Analysis

Separate mixed model analysis were conducted with PROC MIXED of SAS (SAS Inst. Inc, Cary, NC) to determine the effect of actual ME consumed from milk replacer and starter and actual protein consumed from milk replacer and starter and the relationship with calf growth. The dependent variables were MR, starter and combined protein intake from 0-6 wk and 0-8 wk and MR, starter, and combined ME intake from 0-6 wk and 0-8 wk. The independent variables were birth season (spring, summer, autumn, winter), year of birth, ADG class (<0.23, 0.23-0.34, 0.34-0.45, 0.45-0.57, 0.57-0.68, 0.68-0.80, and > 0.80 kg/d) at 6 and 8 wk as well as ADG class nested with herd. Calf trial was a random effect. An example of the SAS input is provided below:

RESULTS AND DISCUSSION

Table 1 shows ADG, DMI, ME intake, protein intake, and first-lactation yield parameters (mean; SD) of the three individual farms and across all the farms. For all farms, 6 wk MR protein, starter protein, and combined protein intake were: 4.7 ± 1.0 kg, 3.6 ± 1.5 kg, and 18.2 ± 5.2 kg, respectively. For all farms, 8 wk MR protein, starter protein, and combined protein were: 4.8 ± 1.0 kg, 9.5 ± 2.7 kg, and 24.1 ± 6.3 kg, respectively. For all farms, 6 wk MR ME, starter ME, and combined ME intake were: 102.1 ± 12.4 Mcal/kg, 57.8 ± 24.6 Mcal/kg, and 160.4 ± 26.4 Mcal/kg, respectively. For all farms, 8 wk MR ME, starter ME, and combined ME intake were: 102.7 ±13.2 Mcal/kg, 151.0 ± 42.2 Mcal/kg, and 253.6 ± 44.1 Mcal/kg, respectively. 6 wk and 8 wk ADG across all farms were: 1.2 ± 0.3 kg/d and 0.7 ± 0.1 kg/d. All calves were managed the same so there was not much difference between Farms A, B, and C in regards to growth rates (Table 1).

Early life protein and metabolizable energy consumption and growth

To analyze protein consumption from both MR and starter we looked into the LS means for each ADG class. For 6 wk ADG class we found that the faster growing calves, those within the higher ADG classes, were significantly consuming more protein. Calves in the lower classes had no difference in protein intake (Table 2). Milk replacer protein consumption was not significant across all classes, but starter protein consumption was a significant driver in growth.

The same procedure was used to analyze ADG at 8 wk. However, for 8 wk we removed ADG class 1, because this class disappeared in this analysis. With ADG class 1 removed, the trend remained the same as it did with 6 wk ADG and protein consumption. At 8 wk the significance of starter protein driving growth was higher (Table 3). We saw a positive correlation between early life combined protein consumption and growth (Figure 1).

Stamey et al. (2012) investigated the influence of starter protein content on growth of dairy calves. They found that starter DMI preweaning was an indicator of ADG the week directly after weaning. No matter the MR feeding program, all calves should consume at least 1 kg of starter DM daily before they are weaned. Our findings, along with Stamey et al. (2012) show the significance starter protein consumption has on ADG and growth of preweaned calves and how that is carried through post-weaning.

As with protein, we analyzed 6 and 8 wk ADG and ME consumption from both MR and starter looking at LS Means. For 6 wk, we saw that the faster growing calves were significantly consuming more starter ME, this significance was greater through 8 wk. There was no significant difference seen for the slower growing calves for both 6 and 8 wk ADG (Table 4 and 5). We saw a positive correlation between early life ME consumption and growth (Figure 2).

While high energy and high fat diets have been shown to impair mammary development and increase fattening (Sejrsen and Purup, 1997), other studies have found ideal protein to metabolizable energy ratios (Brown et al., 2005, Lammers and Heinrichs,

2000) that optimize growth and lessen the risk of fattening and mammary development impairment. Lammers and Heinrichs (2000) found that a CP:ME ratio of 60.9 produced the highest rate of gain and structural growth for heifers. Brown et al. (2005) investigated the effect of increased energy and protein intake. Calves that had increased amounts of energy and protein and higher gain and feed efficiency though 2-8 wk of like and 8-14 wk of life.

Producers can achieve a younger age of puberty and first calving by manipulating preweaning diets and the amount of energy and protein consumed, without the risk of excess fattening (Gabler and Heinrichs, 2003; Lammers and Heinrichs, 2000; Brown et al., 2005). From what was analyzed in our dataset, manipulating a calf's early life ME and protein intake can prove to be beneficial to growth and ADG.

Birth season vs early life protein and metabolizable energy consumption and growth

The effects of birth season on 8 wk MR and starter protein intake and MR and starter ME consumption was investigated in our analysis (Table 6). We saw that fall and winter calves and greater ME and protein consumption. Calves born in the spring consumed the least amount of protein. It appears that calves consumed less than the NRC (2001) requirements. Suggesting that the calves had better feed conversion than what is predicted in the NRC (2001).

Increased consumption of protein and ME is seen in calves in the winter and fall to maintain or increase growth in cold weather (Kuehn et al., 1994). They require more energy for maintenance in harsher environments. In a meta-analysis by Chester-Jones et al. (2017) they found that calves born in the fall and winter had greater starter intake, BW, ADG at 8 wk of life. But similar to the analysis conducted in our study, Chester-

Jones et al. (2017) also showed a high level of variance with their estimates. High levels of variation in these studies comparing seasons suggest that other factors may also contribute to growth in relationship to season.

CONCLUSIONS

Calves that had higher intake of both milk replacer and starter protein and higher intake of both milk replacer and starter ME during the first 8 weeks of life had higher average daily gain. Birth season was a significant factor in intake of both milk replacer and starter protein and ME. However, variance was high in all the estimates suggesting additional factors may affect growth to 8 weeks of age. Our research shows that calves were consuming less than recommended NRC (2001) values. Since variation was high around our estimates, we cannot conclude with confidence that the calves analyzed in our dataset were more efficient than what the NRC (2001) states protein and ME requirements to be. Further investigation is needed to compare current NRC (2001) requirements to what calves are consuming and how that is correlates to average daily gain and calf growth.

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Table 1. Holstein calf milk replacer, starter intake, BW, ADG, and first-lactation production for all 3 Minnesota herds.

	Farm A (n =1,787)		Farm B (n =1,659)		Farm C (n =1,088)		All Farms (n =4,534)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
6-wk Milk replacer intake (kg)	21.9	2.5	22.1	2.8	21.9	2.8	21.9	2.7
6-wk Starter intake (kg)	17.1	7.6	17.8	7.4	18.2	7.4	17.6	7.5
6-wk Milk replacer protein intake (kg)	4.7	0.9	4.7	1.0	4.7	1.0	4.7	1.0
6-wk Starter protein intake (kg)	3.5	1.6	3.7	1.5	3.8	1.5	3.6	1.5
6-wk Milk replacer ME intake Mcal/kg)	101.7	11.7	102.8	12.8	101.9	12.9	102.1	12.4
6-wk Starter ME intake (Mcal/kg)	56.1	25.0	58.4	24.3	59.7	24.2	57.8	24.6
6-wk Combined ME intake (Mcal/kg)	158.5	26.7	161.6	26.3	161.8	25.8	160.4	26.4
6-wk Combined Protein Intake (kg)	8.2	1.8	8.4	1.8	8.5	1.8	8.4	1.8
6-wk ADG (kg/d)	1.2	0.1	1.2	0.3	1.2	0.3	1.2	0.3
8-wk Milk replacer intake (kg)	22.0	2.7	22.2	2.8	22.0	3.0	22.1	2.9
8-wk Starter intake (kg)	44.8	13.0	46.7	12.9	47.1	12.4	46.0	12.9
8-wk Milk replacer protein intake (kg)	4.7	1.0	4.8	1.0	4.8	1.0	4.8	1.0
8-wk Starter protein intake (kg)	9.2	2.7	9.6	2.7	9.7	2.6	9.5	2.7
8-wk Milk replacer ME intake Mcal/kg)	102.4	12.7	103.2	13.3	102.3	13.9	102.7	13.2
8-wk Starter ME intake (Mcal/kg)	146.8	42.5	153.3	42.4	154.4	40.8	151.0	42.2
8-wk Combined ME intake (Mcal/kg)	249.2	43.8	256.4	45.1	256.7	42.2	253.6	44.1
8-wk Combined Protein Intake (kg)	13.9	2.9	14.4	2.9	14.5	2.8	14.2	2.9
8-wk ADG (kg/d)	0.6	0.1	0.7	0.1	0.7	0.1	0.7	0.1

Table 2. ADG Class at 6 wk for Milk Replacer and Starter Protein.

	< 0.23 kg/d LSMean (SE)	0.23-0.34 kg/d LSMean (SE)	0.34-0.45 kg/d LSMean (SE)	0.45-0.57 kg/d LSMean (SE)	0.57-0.68 kg/d LSMean (SE)	0.68-0.80 kg/d LSMean (SE)	> 0.80 kg/d LSMean (SE)
Milk Replacer Protein							
Farm A	4.53^{defg}	4.65^{defg}	4.61^{g}	4.66^{efg}	4.72^{de}	4.90^{c}	5.51^{a}
	(0.18)	(0.12)	(0.11)	(0.11)	(0.11)	(0.11)	(0.13)
Farm B	4.74^{bcdefg}	4.58^{fg}	4.62^{fg}	4.69^{def}	4.73^{d}	4.87^{c}	5.03^{b}
	(0.21)	(0.13)	(0.11)	(0.11)	(0.11)	(0.11)	(0.13)
Farm C	4.12^{efg}	4.67^{defg}	4.66^{defg}	4.64^{fg}	4.70^{defg}	4.86^{c}	5.56^{a}
	(0.33)	(0.14)	(0.11)	(0.11)	(0.11)	(0.12)	(0.14)
All Farms	4.46^{d}	4.63^{cd}	4.63^{d}	4.66^{d}	4.72^{c}	4.87^{b}	5.37^{a}
	(0.17)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
Starter Protein							
Farm A	0.46^{g}	1.11^{f}	2.12^{e}	3.28^{d}	4.36^{c}	5.43^{b}	6.32^{a}
	(0.23)	(0.11)	(3.28)	(0.08)	(0.08)	(0.09)	(0.13)
Farm B	0.31^{g}	1.13^{f}	2.21^{e}	3.24^{d}	4.30^{c}	5.39^{b}	6.58^{a}
	(0.28)	(2.21)	(0.08)	(0.08)	(0.08)	(0.09)	(0.12)
Farm C	0.97^{fg}	1.17^{f}	2.13e	3.33^{d}	4.34^{c}	5.38^{b}	6.34^{a}
	(0.48)	(0.14)	(0.09)	(0.08)	(0.08)	(0.10)	(0.15)
All Farms	0.58^{g}	1.14^{f}	2.17^{e}	3.28^{d}	4.33^{c}	5.40^{b}	6.41^{a}
	(0.21)	(0.09)	(0.08)	(0.07)	(0.07)	(0.08)	(0.10)
Combined Protein							
Farm A	5.14^{i}	5.84^{g}	6.84^{f}	7.96^{e}	9.09^{d}	10.36^{c}	11.99^{ab}
	(0.20)	(0.10)	(0.09)	(0.08)	(0.08)	(0.09)	(0.14)
Farm B	5.14^{i}	5.78^{gh}	6.86^{f}	7.94^{e}	9.04^{d}	10.32^{c}	11.73^{b}
	(0.26)	(0.12)	(0.08)	(0.08)	(0.08)	(0.09)	(0.36)
Farm C	5.19^{hi}	5.94^{g}	6.84^{f}	7.99^{e}	9.06^{d}	10.28^{c}	12.07^{a}
	(0.32)	(0.13)	(0.10)	(0.08)	(0.08)	(0.09)	(0.15)
All Farms	5.14^{g}	5.85^{f}	6.84^{e}	7.96^{d}	9.07^{c}	10.32^{b}	11.91^{a}
	(0.15)	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)	(0.10)

^{abcdefghi} Values in the same row with different superscripts are different ($P < 0.05$)

Table 3. ADG Class at 6 wk for Milk Replacer and Starter ME (Mcal/kg).

	< 0.23 kg/d LSMean (SE)	0.23-0.34 kg/d LSMean (SE)	0.34-0.45 kg/d LSMean (SE)	0.45-0.57 kg/d LSMean (SE)	0.57-0.68 kg/d LSMean (SE)	0.68-0.80 kg/d LSMean (SE)	> 0.80 kg/d LSMean (SE)
Milk Replacer ME							
Farm A	98.90^{defg}	101.21^{def}	100.59^{f}	101.18^{def}	101.95^{d}	103.57^{c}	113.02^{a}
	(2.39)	(1.58)	(1.50)	(1.43)	(1.45)	(1.49)	(1.71)
Farm B	102.66^{bcdef}	100.61^{def}	100.48^{f}	101.65^{de}	101.98^{d}	103.91^{c}	106.16^{b}
	(2.79)	(1.65)	(1.47)	(1.43)	(1.44)	(1.48)	(1.66)
Farm C	91.91^{g}	100.71^{def}	101.24^{def}	100.91^{ef}	101.52^{def}	103.77^{c}	113.16^{a}
	(4.44)	(1.79)	(1.51)	(1.44)	(1.45)	(1.52)	(1.82)
All Farms	97.82^{d}	100.84^{cd}	100.77^{d}	101.24^{cd}	101.82^{c}	103.75^{b}	110.78^{a}
	(2.24)	(1.50)	(1.42)	(1.41)	(1.41)	(1.43)	(1.52)
Starter ME							
Farm A	7.13^{h}	17.48^{g}	34.85^{f}	52.41^{e}	69.55^{d}	86.49^{c}	99.71^{b}
	(3.68)	(1.76)	(1.34)	(1.25)	(1.29)	(1.47)	(2.11)
Farm B	4.82^{h}	18.11^{g}	35.21^{f}	51.65^{e}	68.65^{d}	85.89^{c}	104.53^{a}
	(4.52)	(1.96)	(1.39)	(1.26)	(1.28)	(1.45)	(1.97)
Farm C	15.36^{gh}	18.49^{g}	33.87^{f}	53.30^{e}	69.27^{d}	85.68^{c}	99.94^{ab}
	(7.69)	(2.33)	(1.52)	(1.31)	(1.35)	(1.57)	(2.40)
All Farms	9.10^{g}	18.02^{f}	34.65^{e}	52.45^{d}	69.16^{c}	86.02^{b}	101.39^{a}
	(3.35)	(1.50)	(1.24)	(1.18)	(1.19)	(1.27)	(1.57)
Combined ME							
Farm A	106.14^{g}	118.90^{f}	135.66^{e}	153.84^{d}	171.78^{c}	190.45^{b}	213.10^{a}
	(3.23)	(1.46)	(1.05)	(0.96)	(1.00)	(1.19)	(1.80)
Farm B	107.60^{g}	118.90^{f}	135.93^{e}	153.54^{d}	170.94^{c}	190.14^{b}	211.15^{a}
	(3.98)	(135.93)	(1.11)	(0.97)	(1.00)	(1.16)	(1.66)
Farm C	107.51^{fg}	119.41^{f}	135.34^{e}	154.47^{d}	171.05^{c}	189.84^{b}	213.55^{a}
	(6.83)	(2.00)	(1.24)	(1.03)	(1.07)	(1.29)	(2.06)
All Farms	107.08^{g}	119.07^{f}	135.64^{e}	153.95^{d}	171.26^{c}	190.14^{b}	212.60^{a}
	(2.93)	(1.22)	(0.95)	(0.89)	(0.90)	(0.99)	(1.28)

^{abcdefg}Values in the same row with different superscripts are different ($P < 0.05$)

Table 4. ADG Class at 8 wk for Milk Replacer and Starter Protein (kg).

	0.23-0.34 kg/d LSMean (SE)	0.34-0.45 kg/d LSMean (SE)	0.45-0.57 kg/d LSMean (SE)	0.57-0.68 kg/d LSMean (SE)	0.68-0.80 kg/d LSMean (SE)	> 0.80 kg/d LSMean (SE)
Milk Replacer Protein						
Farm A	5.03[a]	4.71[cde]	4.67[e]	4.69[e]	4.79[bcd]	4.95[a]
	(0.15)	(0.12)	(0.12)	(0.11)	(0.12)	(0.12)
Farm B	4.96[abc]	4.70[cde]	4.67[e]	4.74[cde]	4.74[cde]	4.87[ab]
	(0.17)	(0.14)	(0.12)	(0.11)	(0.11)	(0.12)
Farm C	5.00[abcde]	4.75[bcde]	4.70[de]	4.72[cde]	4.68[e]	4.97[a]
	(0.29)	(0.14)	(0.12)	(0.12)	(0.12)	(0.12)
All Farms	5.00[a]	4.72[bc]	4.68[c]	4.72[bc]	4.74[b]	4.93[a]
	(0.15)	(0.12)	(0.11)	(0.11)	(0.11)	(0.11)
Starter Protein						
Farm A	3.18[f]	5.35[e]	7.44[d]	9.09[c]	10.88[b]	12.95[a]
	(0.25)	(0.15)	(0.11)	(0.10)	(0.11)	(0.13)
Farm B	3.29[f]	5.10[e]	7.25[d]	9.02[c]	10.80[b]	13.11[a]
	(0.28)	(0.19)	(0.12)	(0.11)	(0.11)	(0.12)
Farm C	2.93[f]	5.25[e]	7.33[d]	9.07[c]	10.79[b]	12.92[a]
	(0.58)	(0.21)	(0.13)	(0.11)	(0.11)	(0.13)
All Farms	3.13[f]	5.23[e]	7.34[d]	9.06[c]	10.82[b]	12.99[a]
	(0.24)	(0.13)	(0.10)	(0.10)	(0.10)	(0.10)
Combined Protein						
Farm A	8.22[h]	10.07[g]	12.13[e]	13.81[d]	15.69[b]	17.92[a]
	(0.25)	(0.16)	(0.12)	(0.12)	(0.12)	(0.14)
Farm B	8.26[h]	9.81[g]	11.94[f]	13.78[d]	15.56[bc]	18.00[a]
	(0.28)	(0.19)	(0.13)	(0.12)	(0.12)	(0.13)
Farm C	7.94[h]	10.02[g]	12.05[ef]	13.81[d]	15.49[c]	17.92[a]
	(0.57)	(0.21)	(0.14)	(0.13)	(0.13)	(0.14)
All Farms	8.20[f]	9.98[e]	12.04[d]	13.79[c]	15.59[b]	17.95[a]
	(0.20)	(0.14)	(0.11)	(0.11)	(0.11)	(0.12)

[abcdefg] Values in the same row with different superscripts are different ($P < 0.05$)

Table 5. ADG Class at 8 wk for Milk Replacer and Starter ME (Mcal/kg).

	0.23-0.34 kg/d LSMean (SE)	0.34-0.45 kg/d LSMean (SE)	0.45-0.57 kg/d LSMean (SE)	0.57-0.68 kg/d LSMean (SE)	0.68-0.80 kg/d LSMean (SE)	> 0.80 kg/d LSMean (SE)
Milk Replacer ME						
Farm A	108.98^{a} (2.10)	102.77^{cde} (1.66)	101.38^{d} (1.53)	101.64^{d} (1.51)	102.77^{c} (1.52)	105.50^{b} (1.58)
Farm B	107.65^{ab} (2.26)	102.15^{cde} (1.82)	101.59^{cd} (1.55)	102.26^{cd} (1.51)	102.20^{cd} (1.51)	104.21^{be} (1.56)
Farm C	107.91^{abcd} (3.94)	102.62^{cde} (1.91)	101.81^{cd} (1.58)	101.79^{cd} (1.54)	101.60^{d} (1.53)	105.50^{b} (1.60)
All Farms	108.18^{a} (2.06)	102.51^{c} (1.59)	101.59^{c} (1.50)	101.90^{c} (1.49)	102.19^{c} (1.49)	105.07^{b} (1.51)
Starter ME						
Farm A	50.18^{f} (4.05)	85.35^{e} (2.43)	118.66^{d} (1.83)	145.24^{c} (1.73)	173.49^{b} (1.78)	205.93^{a} (2.06)
Farm B	51.97^{f} (4.56)	81.63^{e} (3.07)	115.68^{d} (1.92)	143.88^{c} (1.75)	172.16^{b} (1.76)	208.75^{a} (2.00)
Farm C	46.21^{f} (9.31)	83.48^{e} (3.40)	117.02^{d} (2.11)	144.85^{c} (1.88)	172.20^{b} (1.86)	205.16^{a} (2.19)
All Farms	49.46^{f} (3.92)	83.49^{e} (2.13)	117.12^{d} (1.67)	144.66^{c} (1.60)	172.62^{b} (1.60)	206.61^{a} (1.73)
Combined ME						
Farm A	159.37^{f} (3.72)	188.35^{e} (2.18)	220.30^{d} (1.59)	247.15^{c} (1.49)	276.59^{b} (1.54)	311.86^{a} (1.82)
Farm B	159.80^{f} (4.21)	184.01^{e} (2.80)	217.53^{d} (1.68)	246.42^{c} (1.51)	274.69^{b} (1.52)	313.40^{a} (1.76)
Farm C	154.32^{f} (8.66)	186.38^{e} (3.11)	219.06^{d} (1.87)	246.92^{c} (1.64)	274.10^{b} (1.62)	311.15^{a} (1.94)
All Farms	158.91^{f} (2.84)	186.60^{e} (1.82)	219.00^{d} (1.42)	246.79^{c} (1.36)	275.20^{b} (1.36)	312.27^{a} (1.48)

^{abcdef} Values in the same row with different superscripts are different ($P < 0.05$)

2

Table 6. Effect of birth season on 8 wk milk replacer and starter protein intake (kg), and milk replacer and starter ME (Mcal/kg).

Variable	Birth season P-value	Spring	Summer	Fall	Winter
8 wk Calf Milk Replacer Protein Intake DM (kg)	0.027	4.86[ab]	4.85[ab]	4.77[b]	4.91[a]
8 wk Calf Starter Protein Intake DM (kg)	<0.0001	6.93[c]	7.06[c]	7.44[b]	7.74[a]
8 wk Calf Milk Replacer ME Intake (Mcal/kg)	0.0003	104.78[b]	104.30[bc]	103.29[c]	106.1[a]
8 wk Calf Starter ME Intake (Mcal/kg)	<0.0001	110.37[c]	112.34[c]	118.62[b]	123.33[a]
8 wk Combined Protein Intake DM (kg)	<0.0001	12.57[c]	12.67[c]	12.98[b]	13.41[a]
8 wk Combined ME Intake DM (Mcal/kg)	<0.0001	239.54[c]	241.85[c]	246.69[b]	250.00[a]

[abc] Values in the same row with different superscripts are different ($P < 0.05$)

Figure 1. ADG Class at 6 wk vs. Combined Protein Intake

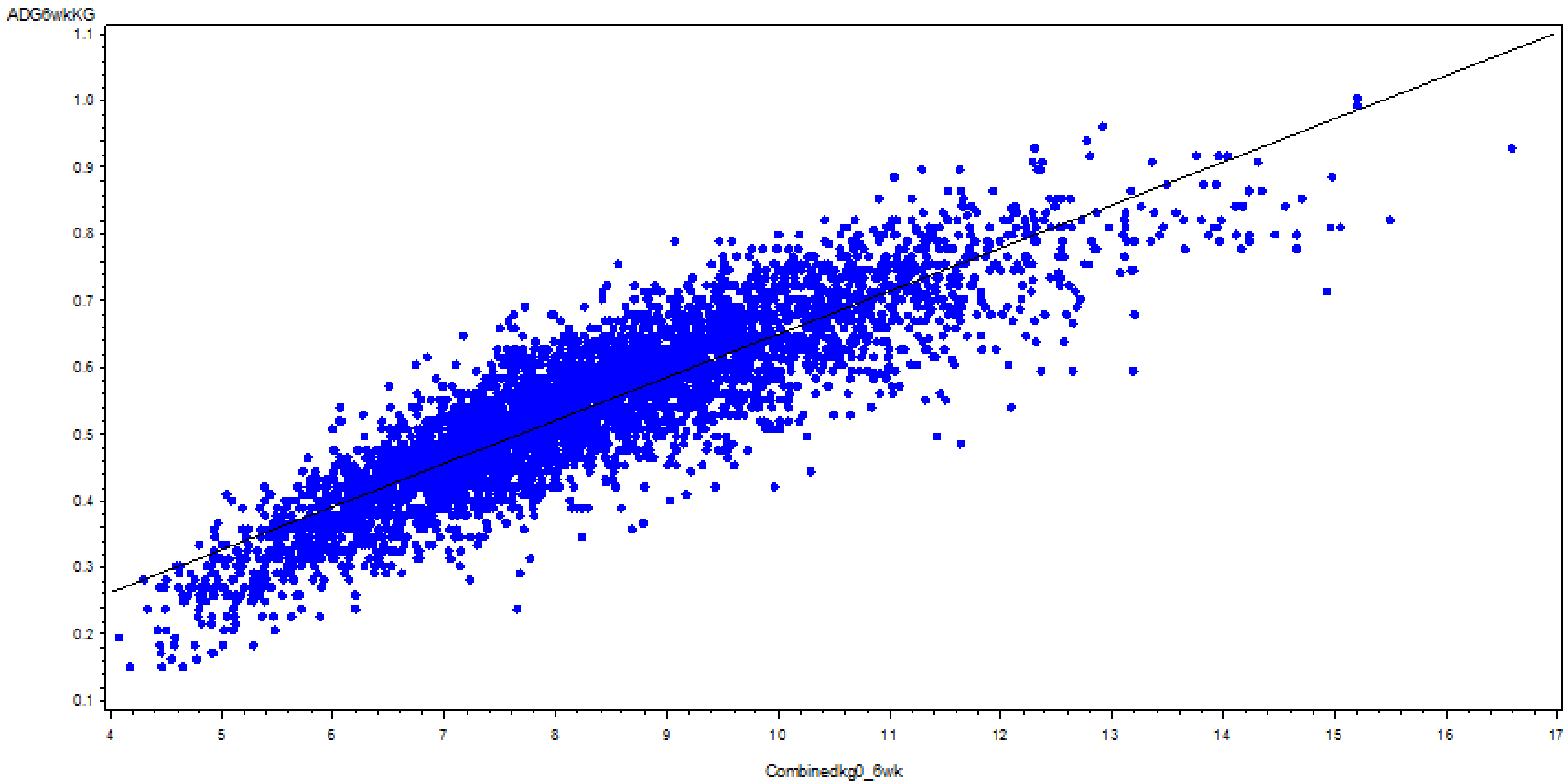
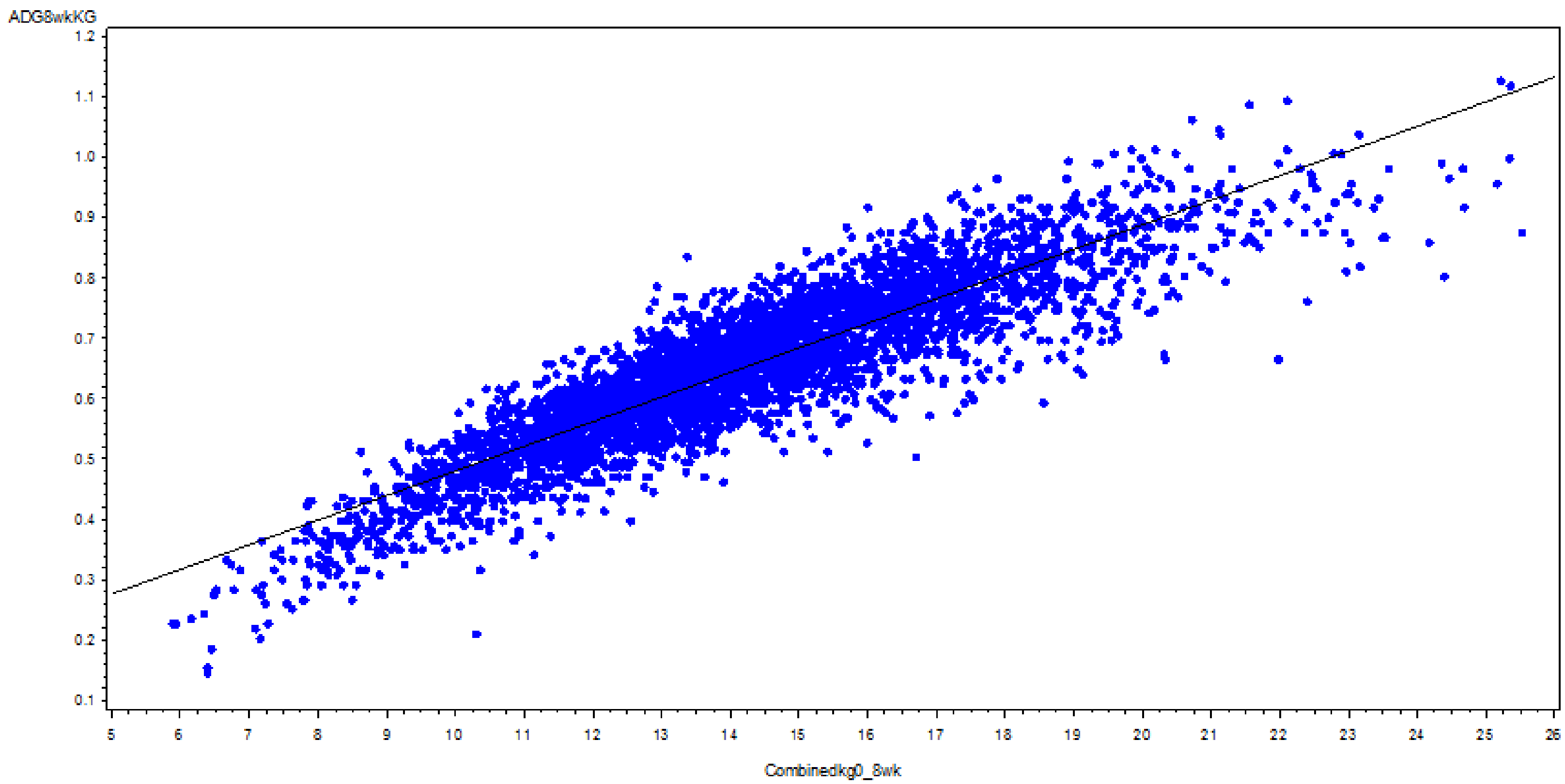


Figure 2. ADG Class at 6 wk vs. Combined ME Intake



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